Multimedia Collaborative Remote Consultation Tools via Gigabit Wide Area Networks in Teleradiology

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ABSTRACT: Many rural hospitals would like continuous coverage for radiology services. Some of these hospitals are, in fact, without a radiologist. This shortcoming can be addressed by developing a diagnostic-quality, cost-effective system for teleradiolgy. As deployment of wide area and local asynchronous transfer mode (ATM) networks continues, workstation performance accelerates and costs decrease, the availability of teleradiology systems becomes limited by upper-layer protocols, disk speed and the dynamic range of computer displays.

If data base functionality of a picture archive and communications system (PACS) are ignored, teleradiology is becoming a reality. This paper deals with extending a University of Arizona teleradiolgy and teleconsultation application to the widest possible area by using high-performance-satellite communications and traditional telephone service.

1. Introduction

Teleradiology systems of the future will be based on electronic imaging systems composed of multimedia information[1]. Sophisticated teleradiology users are using more multimedia information requiring scientific visualization systems, such as 3-D stereotactic guidance for neurosurgical procedures, and real-time visualization of ultrasound image data. These systems also require local and wide area megabit-bandwidth communications networks. Medical imaging modalities in radiology require large volumes of information in the acquisition, storage, display, transfer, and retrieval of multimedia data. Standards for communications of medical imaging information are now becoming available[2]. The storage and retrieval of multimedia information requires access by some form of distributed database management systems, which are transparent and simple to the user. Through the access of this information, users can perform collaborative remote consultation and diagnosis between physicians located at different geographical locations. In addition, patient multimedia information must be protected by security and privacy features of the system. In teleradiology systems, we define multimedia information by the different textual and visualization forms it takes and the display method used. Patient demographic information is textual in nature. Modality images can take on different forms, such a digital radiographic display in raw pixel form. There many digital image display formats, such as the Graphics Interchange Format (GIF), Tagged Image File Format (TIFF), and ACR-NEMA DICOM Data Dictionary[2]. Case studies in MRI contain sequences of images, mostly at resolutions less than 512x512 pixels per image. MRI and CT scanner image sequences used to construct 3-D stereo images require many frames. Digitized video sequences at 30 frames per second can generate mega-bytes of information in a few second sequence. Digitized voice for diagnosis in a remote consultation session can also generate many mega-bytes of voice packets. This type of medical informatics multimedia information also requires synchronization in the content of its use. Medical imaging information systems are inherently distributed as a result of the multitude of system and data resources. This migrates database subsystem solutions toward distributed, or at least federated architectures[a].

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In this paper, four key technologies are examined.

1. Distributed computing environment.
2. Gigabit network infrastructure.
3. Multimedia collaborative remote consultation and diagnosis tools.
4. Security and privacy features for multimedia patient imagery and demographics.

This is followed by a proposed architecture for teleradiology.

2. Distributed Computing Environments

There has been much progress in the development of distributed computing environments in the last 10 years, especially in heterogeneous processing[3][4]. The Open System Foundation Distributed Computing Environment (OSF DCE) is an integrated set of services that supports the development, use, and maintenance of distributed applications[5]. It is independent of operating system platforms and computer networks. The OSF DCE allows applications to use distributed services over a heterogeneous computing environment. The architecture is bottom-up from operating system and transport services to the user applications. An application can be any user service, such as a database management system or a visualization tool for imaging processing. The OSF DCE architecture allows vertical interfaces for security and management. The services provided by OSF DCE are categorized into two parts:

1. Fundamental Distributed Services. These include tools for software developers to create end-user applications: Remote procedure calls, Naming service, Time service, Security service, and Threads service.
2. Data Sharing Services. These include functions which can be used by the end-users and require no programming: Distributed file system, Diskless support, and MS-DOS support services.

The OSF DCE holds great promise as a basis for developing a transparent DCE for teleradiology applications over today's networks and the emerging gigabit wide area networks.

3. Gigabit Networks

DARPA and NSF have been instrumental in funding important research programs in packet switched networks. The original ARPANET developed in the 1970's evolved into the Defense Data Network (DDN) and has become the Internet. The TCP/IP protocols are currently used in the Internet[6]. The NSFNET is part of the Internet and was increased from 13 nodes to 16 nodes in 1990, and will include 19 T3 nodes by 1993. Current research programs, funded by NSF and DARPA, on gigabit networks will result in the National Information Infrastructure (NII)[a] in the late 1990's. In these programs, there are five testbeds which are investigating several basic components of NII and several application areas[7]. Research in broadband ISDN (B-ISDN) is currently being conducted by major telecommunications vendors and some universities. Research in basic transmission mechanisms in Asynchronous Transmission Mode (ATM) and Synchronous Optical Network (SONET) will allow mega-bit transmission speeds for wide area networks[9]. The promise of Gbps transmission rates makes B-ISDN a candidate for the NII backbone. In fact, the state of North Carolina will deploy a major ATM network, the North Carolina Information Highway (NCIH) in June of 1994 to support Internet connectivity as well as advanced services such as teleradiology.

4. Remote Consultation and Diagnosis Collaborative Tools

The Computer Engineering Research Laboratory (CERL) at the University of Arizona has been performing PACS research for medical imaging since 1984. CERL has developed the Global PACS. A Global PACS environment combines imaging

[8] A federated system is one which allows informatics islands to continue operating whether or not the meta-system is operating

[a] Formerly known as the National Research and Educational Network (NREN)

equipment, viewing workstations, database archive system and a national high speed fiber optic backbone network. Remote Consultation and Diagnosis (RCD) software, an essential element of a Global PACS, allows two radiologists at different geographical locations to perform diagnosis on the same patient image. The software defines a distributed computing environment using TCP/IP, sockets, Remote Procedure Calls (RPC), and a distributed file management system.

The system consists of three major parts, the Local Workstation (WS), Remote WS Consultant, and Database Archive System(DBAS), which collaborate in a distributed computing environment over the Internet. The remote consultation and diagnosis operation has been performed over the Internet between the radiology departments of the University of Arizona College of Medicine and the Bowman Gray School of Medicine of Wake Forest University. Tests by Kim show average response times for framing information less than 250 milliseconds over a 24 hour period[8]. The project demonstrates a distributed computing environment based on TCP socket connections and remote procedure calls. This work is a significant start for remote consultation and diagnosis in teleradiology, since it provides us the application software and basic RPC commands for real-time collaboration over the Internet.

The RCD software provides access to rural areas using a modem and the Serial Line Internet Protocol (SLIP) in the remote workstation. The SLIP protocol allows the remote workstation to function actually as one on the Local PACS network. The telephone line is slow for image transfer, however it still provides the real-time image annotation commands during the remote consultation session. This is one mechanism for rural access proposed for the teleradiology system.

5. Security

Eventually, the security and privacy features of teleradiology must be taken into account. This is being mentioned as many systems do not concern themselves with security at this time, relying on whatever security features are used in their UNIX workstations which exceeds most personal computer security features. However, many of the security features can be implemented under the OSF DCE security services. The design areas that must be considered are

- user and physical access,
- communications network,
- database, and
- management and administration.

The security measures cannot be covered in this paper but are covered elsewhere[10]. It is mentioned here due to the importance of security to the teleradiology systems.

6. Proposed Architecture

6.1 Physical and Data Link Layers

The data link connectivity is shown in Figure 1. There are three high performance network infrastructures:

1. Internet and NSFNET, 45 Mbps.
2. Advanced Communications Technology Satellite (ACTS) High Data Rate Terminal (HDRT), 155-622 Mbps, linking the ATM-based networks for the distributed database and remote consultation and diagnosis applications.
3. NII, Gbps demonstrating multimedia applications and providing a model for scalability to expanded teleradiology users.

Because the NSFNET is well understood, and the NII is an evolution of this, the remainder of the section deals with ACTS and normal telephone service.

6.1.1 Use of the NASA ACTS for High Performance Networking

The availability of gigabit wide area networks provides exciting potential for teleradiology. The NII will provide gigabit networking by the late 1990's. There are several communications and protocol technologies which are candidates for the NII, including SONET and ATM islands using light weight protocols. NASA's ACTS can be used to access suf-

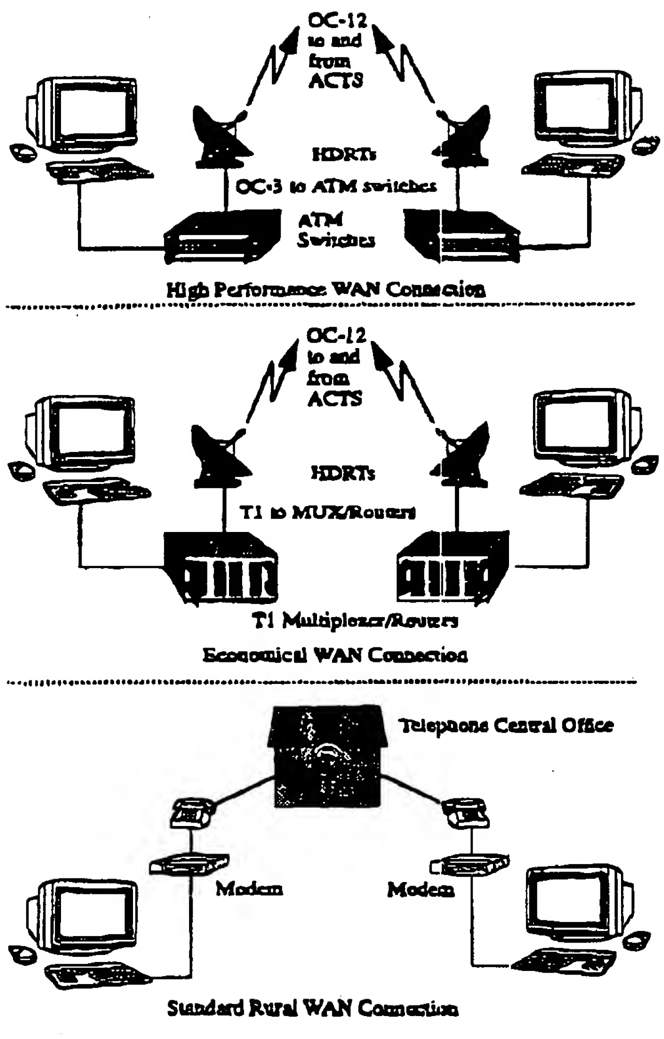

Figure 1 : Physical and Data Link

ficient bandwidth for teleradiology applications as well as the NII's gigabit capability[11]. The ACTS satellite is due to be operational by January 1994. In this section, the gigabit networking features of the ACTS and the proposed network interface to the ACTS earth stations are summarized.

6.1.2 Gigabit Networking Features of the ACTS

ACTS provides multi-beam antenna coverage of the Continental United States using a 900 MHz transponder bandwidth and a microwave switch matrix for connecting multiple nodes. ACTS can support an aggregate data rate of 622 Mbps on three simplex satellite channels through terrestrial interfaces at SONET OC- 12/12c (622 Mbps) and OC-3/3c (155 Mbps) data links. The ACTS satellite has five receive and five transmit antenna ports, called 1) West Family, 2) East Family, 3) Atlanta, 4) Tampa, and 5) Cleveland. The latter three areas are serviced by fixed beam antennas. The West and East Family area are covered by beaming forming antennas which hop to multiple spot locations. The West Family includes a steerable antenna. These antenna ports can be interconnected through the on-board TDMA Baseband Processor or the 3x3 channel Microwave Matrix Switch. Each channel is capable of a maximum throughput of 622 Mbps. Each TDMA channel can be subdivided into four subframes of 155 Mbps each.

6.1.3 Network Interface to the ACTS Earth Stations for More Economical Connections

Earth station communications to the ACTS is done by a T1 VSAT system or a High Data Rate Terminal (HDRT) system. The T1 VSAT system uses DS-0 (64kbps) and DS-1 (1.544 Mbps) interfaces to communicate with standard communications systems, such as an ISDN switch. It has a total throughput capability of T1 plus four 64 Kbps circuits, for a total of 1.792 Mbps. The T1 VSAT system also has an optional primary rate (23B+D) interface for ISDN systems. The T1 VSAT system represents the low cost, low performance interface to ACTS. The HDRT is the high performance interface to the ACTS and includes three simplex OC-12 links and twelve OC-3 links to user equipment. The use of these interfaces through the ACTS depends on which areas are being serviced by the ACTS antennas beams. The network interfaces to the two earth stations will be designed to connect to high speed local area networks and connection to the Internet.

6.1.4 Standard Rural Connection

Some areas will not have ISDN deployed in the near future, but do have normal telephone service. The RCD software system's reach can be extended to rural areas using these existing phone lines. V.32, V.32bis, V.32terbo, and V.fast modems can be used with SLIP for remote consultation at remote areas. This makes the teleradiology system scalable from

the 9.6 Kbps available from V.32 modems to the 24.4 Kbps available from V.fast modems. It also gives access to the 56 Kbps digital lines and the ISDN bandwidth offerings when they become available to rural areas.

6.1.5 Workstations and Workstation Interfaces

The Servers and Client workstations must be interfaced to the ATM switches to provide megabit bandwidths to the ACTS High Data Rate Terminal (HDRT). The HDRT must be integrated to the ATM switch which interfaces to the workstations. This provides the multiple OC-3 links of the ACTS to an ATM switch. From here the information can be distributed to ATM multimedia workstations or to IEEE 802.X LANs.

The use of OC-3 links and some multimedia workstations becoming available in the first quarter of 1994 provide 640x480x8 bit frames at a frame rate of 15 to 20 frames per second over ATM. This is being done in development laboratories now. This means that real-time ultrasound teleradiology is becoming possible using standard computer systems. This concept was heralded in an earlier paper describing digital radiology costs[12].

6.2 Network and Transport Layers

6.2.1 Legacy Protocols

Initially, TCP/IP is used over the Internet for development of the teleradiology subsystem. However, recognizing the limitations of TCP/IP over the current Internet for multimedia communications drives the design towards next-generation protocols, such as XTP[13] and other light weight protocols[6][14][15] to handle the megabit and gigabit bandwidth of the ACTS and NII. By specifying TCP/IP, however, it will have a clear evolutionary path to emerging high performance networks such as the fiber distributed data interface (FDDI), Follow-on-FDDI, ATM, and switched fiber channel while supporting SLIP access to lower speed telecommunications services. It also provides a path for using evolving high performance protocols such as XTP which support many of the new multimedia applications.

6.2.2 Next Generation Protocols

The Xpress Transfer Protocol (XTP)[13][14] offers many advantages for a digital radiology and teleradiology systems[16]. Placing X Windows on top of the XTP protocol does two important things. First, it allows the University of Arizona's RCD to operate without any major changes, other than changing single socket call to invoking XTP instead of TCP/IP as the protocol and a recompiling the code. Second, by using XTP, many multimedia features can be exploited[17] including multipeer remote consultation and diagnosis using XTP's multicast features.

XTP provides mechanisms for upper-layer protocol efficiency. For example, Nagle's algorithm prevents the sending of hundreds of small X events, such as a response to a user rapidly moving a mouse. In normal X Windows, this results in a message sent for each sampling period which is dutifully responded to by the X-server. This results in a phenomena producing much network traffic of small packets that is sometimes called tinygram blizzards. The Nagle's algorithm collects X-events and sends them when a sufficient packet is created. This is efficient but is visually unpleasant. XTP offers several mechanisms to could reduce unnecessary acknowledgments of insignificant X-events[18] while maintaining visual continuity.

6.3 Upper Layers

Imaging should be supported by X Windows as it is implemented on most modern computers and available on personal computers. The OSF DCE should be used to maximize the independence of operating system platforms and computer networks. This provides a federated system services over a heterogeneous computing environment. The architecture is bottom-up from operating system and transport services to the user, or upper- layer applications.

Voice will have to be included with the high performance offering. This will necessitate the use of a next generation protocol as synchronization becomes an issue. In addition to synchronized voice, image annotation to the remote consultation application is desirable. This will allow session recording

and playback for remote consultation sessions with adequate bandwidth. Eventually, the digital transcription may be part of the patient demographics in the database system. The sessions can be played back in the future for review, teaching, and research purposes.

Control of isochronous bandwidth in the order of 80 Mbps is necessary for real-time ultrasound. In this application, a radiologist directs the technologist to place transducers in optimal positions and requests the optimal diagnostic protocol *during an examination*. This decreases the time of the examination and allows the diagnosis to be done at the end of the examination instead of the time it takes to use overnight mail for a NTSC video cassette.

7. Conclusion

Teleradiology systems could establish a distinct and unique service. It could allow for more rapid interpretation of examinations performed at affiliated clinics. As Blue Cross/Blue Shield requirements for timely film interpretation become more stringent, radiologists could review and interpret films at home during the evening hours. Placement of the system in affiliated clinics (it would be a portable device that could travel with faculty members) could provide the clinical staff with radiologic input for more efficient evaluation and treatment planning. Overreading services, call coverage (evening, weekends), or "staffing" of smaller rural hospitals who presently don't have full time radiologists could be provided. Remote ultrasound interpretation should be available during the first quarter of 1994 in areas with ATM OC-3 offerings.

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